CHAPTER 4
DESCRIPTION OF THE AFFECTED ENVIRONMENTS

This chapter describes the affected environments at the Waste Isolation Pilot Plant (WIPP) site and at the ten major generator-storage sites. The WIPP site is discussed in detail with emphasis on the changes that have occurred and new information that has been determined since the publication of the *Final Supplement Environmental Impact Statement for the Waste Isolation Pilot Plant* (SEIS-I) in 1990 (DOE 1990).

4.1 EXISTING ENVIRONMENT AT THE WIPP

The passage of the WIPP Land Withdrawal Act (LWA), results of recent environmental studies, and changes to various aspects of the existing environment have generated new information concerning the environment at the WIPP site. The following sections update Sections 4.1.1 through 4.3.5 of SEIS-I (DOE 1990).

4.1.1 Land Use and Management

The U.S. Department of Energy (DOE or the Department) defines the region of influence (ROI) for land use impacts as WIPP plus ". . . the site and the area immediately adjacent to the site" (DOE 1997b).[1] Thus, for WIPP, the area of consideration for land use includes privately owned ranches and Bureau of Land Management (BLM) lands, including some leased as mineral and grazing lands immediately adjacent to the WIPP site. The *Final Environmental Impact Statement for the Waste Isolation Pilot Plant* (FEIS) (DOE 1980) states that almost 7,700 hectares (19,000 acres) of land surrounding WIPP were committed to the WIPP project. It notes that the dominant use of the land within 16 kilometers (10 miles) of the site is grazing, with lesser amounts used for oil and gas extraction and potash mining. BLM owns most of this land. Two ranches are located within 16 kilometers (10 miles)

CHANGES IN SITE LAND USE AND MANAGEMENT

Since publication of SEIS-I, DOE has made the following changes in land use. These changes are largely due to the planning-basis WIPP Waste Acceptance Criteria (WAC) and the Land Management Plan.

- *Wildlife Management* - DOE initiated a multi-year research effort to document the population and ecology of several species, and additional seeding of reclamation sites was undertaken.
- *Cultural Resources Management* - DOE created a comprehensive WIPP archeological database.
- *Vegetation Management* - DOE now monitors vegetation for evidence of stress induced by climate and salt tailings.
- *Rights-of-Way* - In 1994, DOE requested and was granted permission by BLM to construct a short access road.
- *Emergency and Facility Security* - DOE has published three plans on emergency and facility security.
- *Groundwater Surveillance* - DOE has installed seven new wells to monitor water quality.

[1] Currently this ROI includes only two working ranches. No towns are included.

of the WIPP site while the closest town, Loving, New Mexico, is 29 kilometers (18 miles) away. The federal government or the State of New Mexico owns most of the land within 50 kilometers (30 miles) of the WIPP site. Within 80 kilometers (50 miles) of the site, there is dryland farming, irrigated farming along the Pecos River, and some forest, wetland, and urban land (see Figure 4-1).

SEIS-I (DOE 1990) notes the release of approximately 4,450 hectares (11,000 acres) of previously restricted land for unrestricted use, allowing exploration for and development of mineral resources and permanent habitation. It describes a land withdrawal boundary, which defines the WIPP site, as encompassing 16 sections (4,146 hectares [10,240 acres]) of federal land in Township 22 South, Range 31 East (Figure 4-2). This boundary was delineated so as to extend at least 1.6 kilometers (1 mile) beyond any WIPP underground development.

The type of land use surrounding WIPP has not changed substantially since the preparation of SEIS-I, although the level of development has increased. The site has been divided into four areas under DOE control (Figure 4-2). A chain-link fence surrounds the innermost "Property Protection Area," which includes the surface facilities. Surrounding this inner area is the "Exclusive Use Area," set off by a barbed-wire fence. Enclosing these areas is the "Off-Limits Area," which is unfenced to allow livestock grazing but, like the other two, is patrolled and posted against trespass or other land uses. Beyond the "Off-Limits Area," but within the 16-section WIPP site, the land is managed under the traditional public land use concept of multiple use. Mining and drilling for purposes other than support of the WIPP project, however, are restricted (DOE 1995d).

On October 30, 1992, the President signed into law the LWA (Public Law 102-579). This Act transferred responsibility for management of the WIPP withdrawal area from the Secretary of the Interior to the Secretary of Energy. The land is permanently withdrawn from all forms of entry, appropriation, and disposal under the public land laws and is reserved for uses associated with the purposes of WIPP. LWA establishes certain rights and responsibilities, one of which was the preparation of a Land Management Plan published in 1993 (DOE 1993a).

DOE's WIPP Land Management Plan incorporates the restrictions of the LWA and the DOE Memorandum of Understanding (MOU) with the BLM. The Land Management Plan establishes management objectives and planned actions for the use of the withdrawn land until the end of the decommissioning phase. The plan promotes the concept of multiple-use management for the surface area of the withdrawn land and establishes a goal of minimizing land use restrictions where possible. The plan also provides opportunity for participation in the land use planning process by the public, and local, state, and federal agencies.

The Land Management Plan lists 13 areas of concern: wildlife, cultural resources, grazing management, recreation, mining and oil and gas production, rights-of-way, access, emergency and facility security, fire management, water service, groundwater surveillance, salt tailings, and reclamation. The following is a summary of the progress made toward implementing this plan. Details of these actions can be found in the *Waste Isolation Pilot Plant Site Environmental Report for Calendar Year 1994* (DOE 1995d).

Recent efforts in the area of wildlife management include initiating a multi-year research investigation into the ecology and life history of resident raptor populations, with emphasis on the Harris hawk (*Parabuteo unicinctus*); appraisals of populations of small nocturnal mammals; and the additional seeding of reclamation sites to increase soil stabilization.

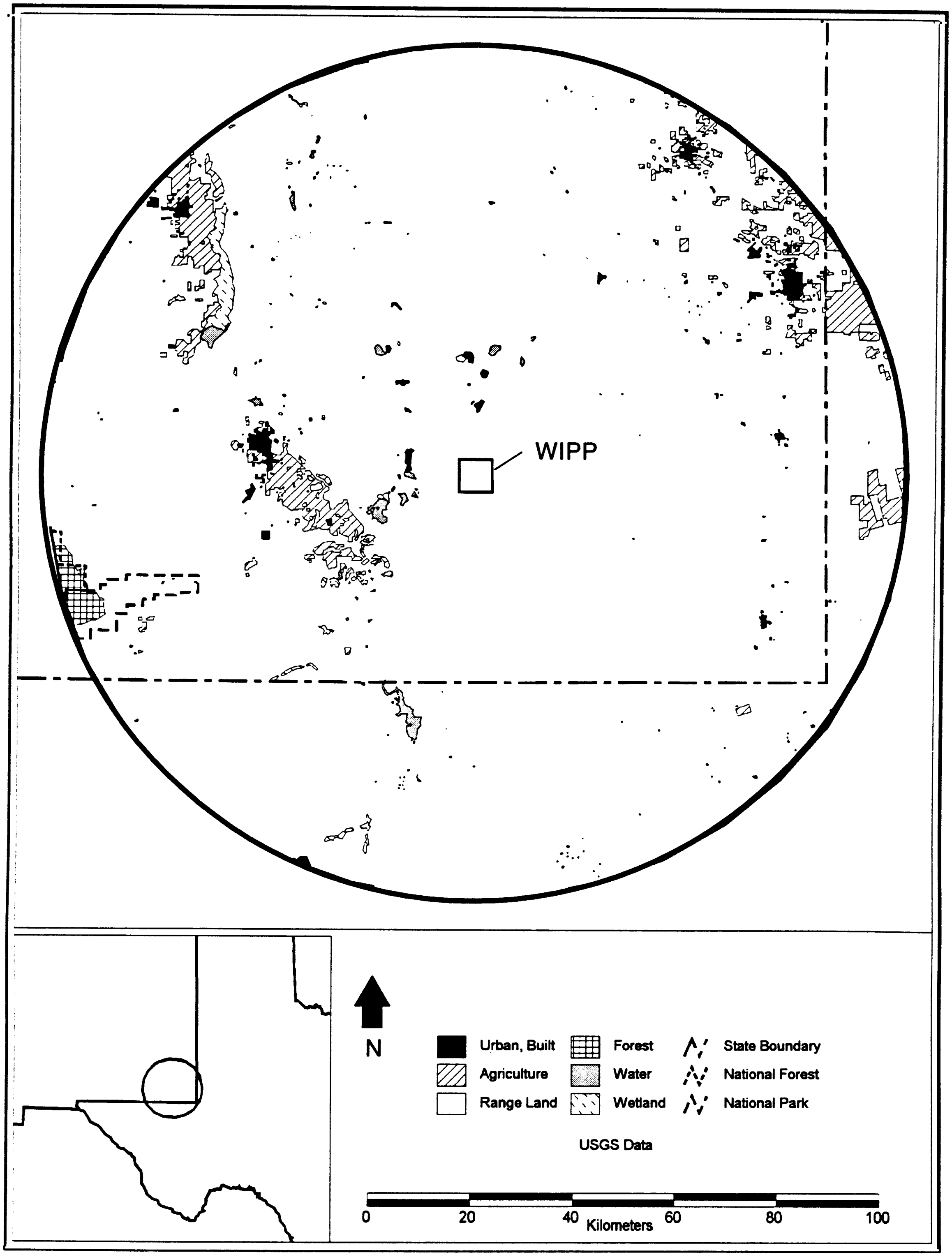


Figure 4-1
Land Use Within 80 Kilometers (50 Miles) of WIPP

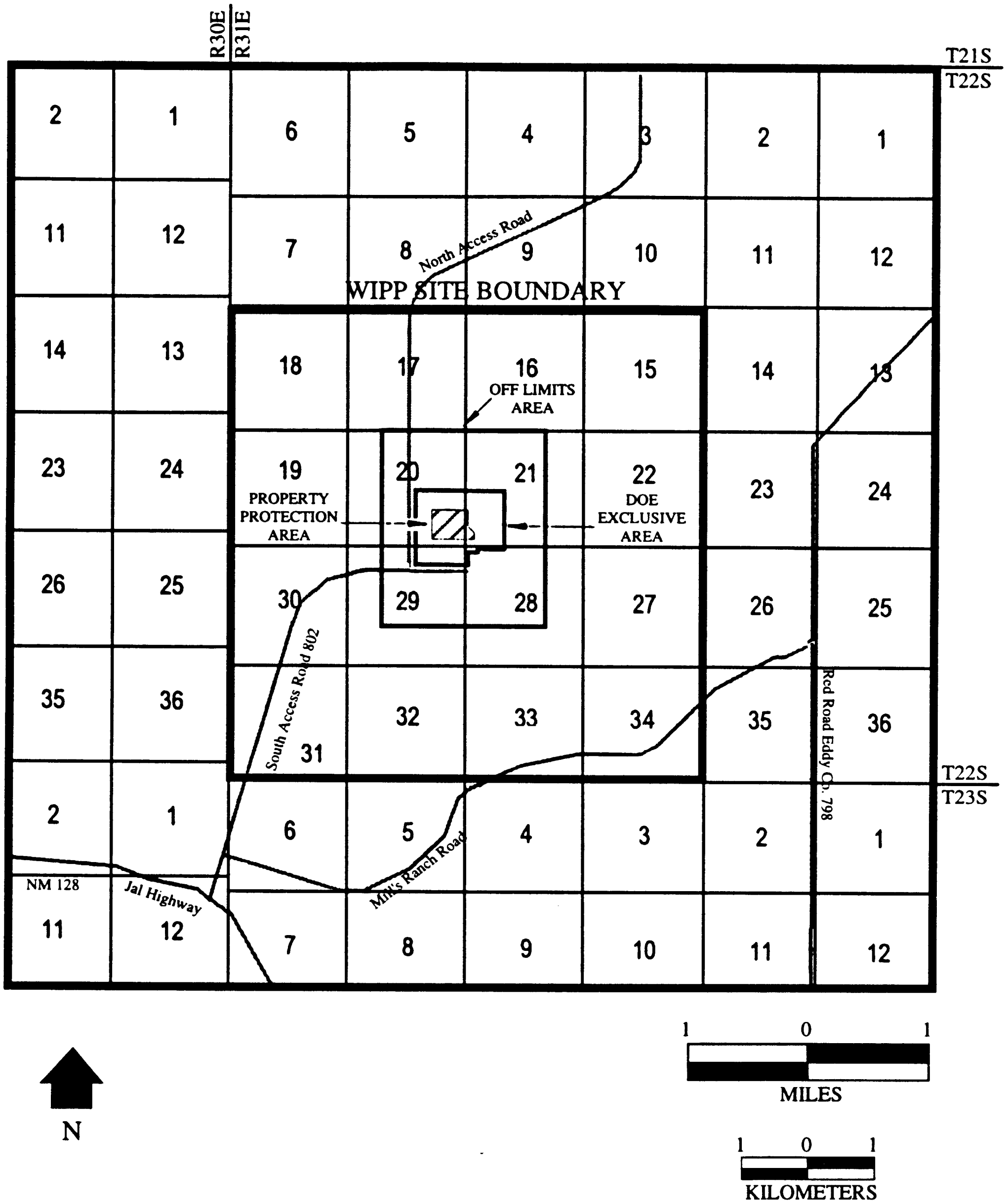


Figure 4-2
WIPP Areas

DOE also recently entered into a Joint Powers Agreement with the State of New Mexico (signed by the State Historic Preservation Officer), pursuant to Sections 106 and 110 of the National Historic Preservation Act and other statutes.

DOE's intent concerning grazing management is to continue current management practices unless a need develops to modify them. To that end, planned actions include continuing vegetative monitoring in the withdrawal area, continuing the management of grazing allotments under the principles of multiple-use management and sustained yield, and continuing range management practices in accordance with appropriate acts and regulations.

DOE intends to maintain recreation resource values and to continue to provide opportunities for individuals to participate in recreational activities within designated parts of the withdrawal area. Planned actions include environmental monitoring of the withdrawal area, regulating off-road vehicle use, and determining the potential effect of anticipated projects or other activities on the visual quality of the landscape. DOE would also allow hunting and trapping in accordance with applicable regulations.

The Land Management Plan incorporates the restrictions of the LWA. The subsurface of the withdrawal area is reserved for exclusive use of WIPP. No surface or subsurface mining unrelated to the WIPP project, including slant drilling from outside the boundary area, is permitted. The exception is two tracts of land within the withdrawal area that are leased from BLM for oil and gas development below 1,829 meters (6,000 feet). In instances where operators seek permits to drill or mine at a location close to the withdrawal boundary, DOE will request drilling information to detect any potential for subsurface encroachment into the WIPP repository. Should there be potential for encroachment, the operator will be required to modify the drilling activity in accordance with existing memorandums of understanding or similar agreements. Two active mining and drilling leases within the Land Withdrawal Area may be purchased by DOE.

BLM administers rights-of-way in coordination with DOE. The objective is to ensure safe and adequate access to WIPP while protecting the security of personnel and facilities. Consideration is also being given to closing parts of some access roads to protect the health and safety of the public. In 1994, DOE requested and was granted permission to construct short access roads from main roadways to the sites of wells.

Changes concerning emergency and facility security preparedness include implementing plans to minimize impacts during emergencies. These plans include the WIPP Emergency Plan (WP 12-9), the WIPP Resource Conservation and Recovery Act (RCRA) Contingency Plan (WP 02-12), and the WIPP Security Plan.

Fire management is concerned with wildfires in the withdrawal area. The Land Management Plan provides for immediate notification of the BLM Carlsbad Fire Control Officer upon detection of a wildfire. WIPP personnel may call upon help from various sources or may opt to have BLM fight a wildfire, if conditions warrant that choice.

Water service for WIPP is provided by a DOE-constructed water line from Carlsbad's system to the WIPP site and is made possible by a contract between DOE and the City of Carlsbad.

The groundwater surveillance program adjusts surveillance activities, if necessary, and plugs and seals wells when they are no longer necessary. In support of this program, seven new wells were installed for water quality sampling.

The Land Management Plan provides for the management of the salt pile in an environmentally sound manner until such time as a determination is made on its disposition. Salt backfill is not required for subsidence control or repository performance but may be placed into the repository for final disposition. Management of the salt pile may include monitoring vegetation for evidence of stress from salt; selling or disposing of unneeded salt under the Materials Act of 1947; ripping, leveling, and adding topsoil to the salt stockpile base; and reseeding with seed mixes reflecting indigenous plant species.

Recent activities in the area of land reclamation have included decommissioning numerous fenced areas, removing rebar from study areas to alleviate safety hazards to personnel and livestock, and carrying out additional reclamation measures in selected problem areas such as drainages and eroded slopes.

4.1.2 Air Quality, Climate, and Noise

The Environmental Protection Agency (EPA) has classified Eddy County, New Mexico, where WIPP is located, as an attainment area for all six of the criteria pollutants under the National Ambient Air Quality Standards (NAAQS). WIPP is also in a Class II Prevention of Significant Deterioration (PSD) area, and any new sources of emissions would have to adhere to the standards for such an area (META/Berger 1995). The Class I PSD areas nearest to WIPP are: Carlsbad Caverns National Park, which is approximately 61 kilometers (38 miles) southwest of WIPP, and Guadalupe Mountains National Park, which is approximately 100 kilometers (62 miles) southwest of WIPP.

The measurement of selected air pollutants at WIPP began in 1976 and was reported in FEIS (DOE 1980). SEIS-I (DOE 1990) stated that seven classes of EPA-regulated atmospheric gases had been monitored since August 27, 1986. These gases are carbon monoxide (CO), hydrogen sulfide (H_2S), ozone (O_3) precursors, oxides of nitrogen (NO_x), and sulfur dioxide (SO_2). Total suspended particulates (TSP) were also monitored in conjunction with the air monitoring programs of EPA's Regulatory and Environmental Surveillance Programs. As reported in SEIS-I, the results of this monitoring program indicated that air quality in the area of WIPP usually met state and federal standards. SEIS-I indicated that, during periods of high wind and blowing sands, the TSP standards were occasionally exceeded, but the ambient air quality standard for sulfur dioxide had been infrequently exceeded.

Air quality monitoring data collected since 1990 are summarized in annual WIPP site

CHANGES IN AIR QUALITY MONITORING

Since publication of SEIS-I, the following changes have occurred:

- *Monitoring of Pollutant Gases* - On October 30, 1994, after DOE notified EPA, monitoring of criteria air pollutants at the WIPP Ambient Air Monitoring Station was discontinued because it was no longer required by regulation.
- *Volatile Organic Compound (VOC) Monitoring Program* - The VOC monitoring program was established at WIPP in 1991 after the EPA determined that air migration of VOC target compounds would be a potential concern during both testing and operations at the facility.

environmental reports (DOE 1992, 1993b, 1994a, 1995d, and 1996d). WIPP has completed inventories of potential pollutants and emissions in accordance with EPA and New Mexico Air Quality Control Regulations (AQCR). Based on these inventories, WIPP has no permitting or reporting requirements at this time except for those applying to two primary backup diesel generators. An AQCR operating permit was issued for the two diesel generators in 1993 (DOE 1995d). These diesel generators are assumed to emit four pollutants (nitrogen dioxide (NO_2), SO_2, CO and particulate matter less than or equal to 10 micrometers in diameter [PM_{10}]) and have strict limits on emissions for these pollutants (see Section C.3.2). On October 30, 1994, DOE, after notifying EPA, ceased to monitor criteria air pollutants at the WIPP Ambient Air Monitoring Station because there was no longer a regulatory requirement to do so. TSP monitoring continues weekly at off-site locations.

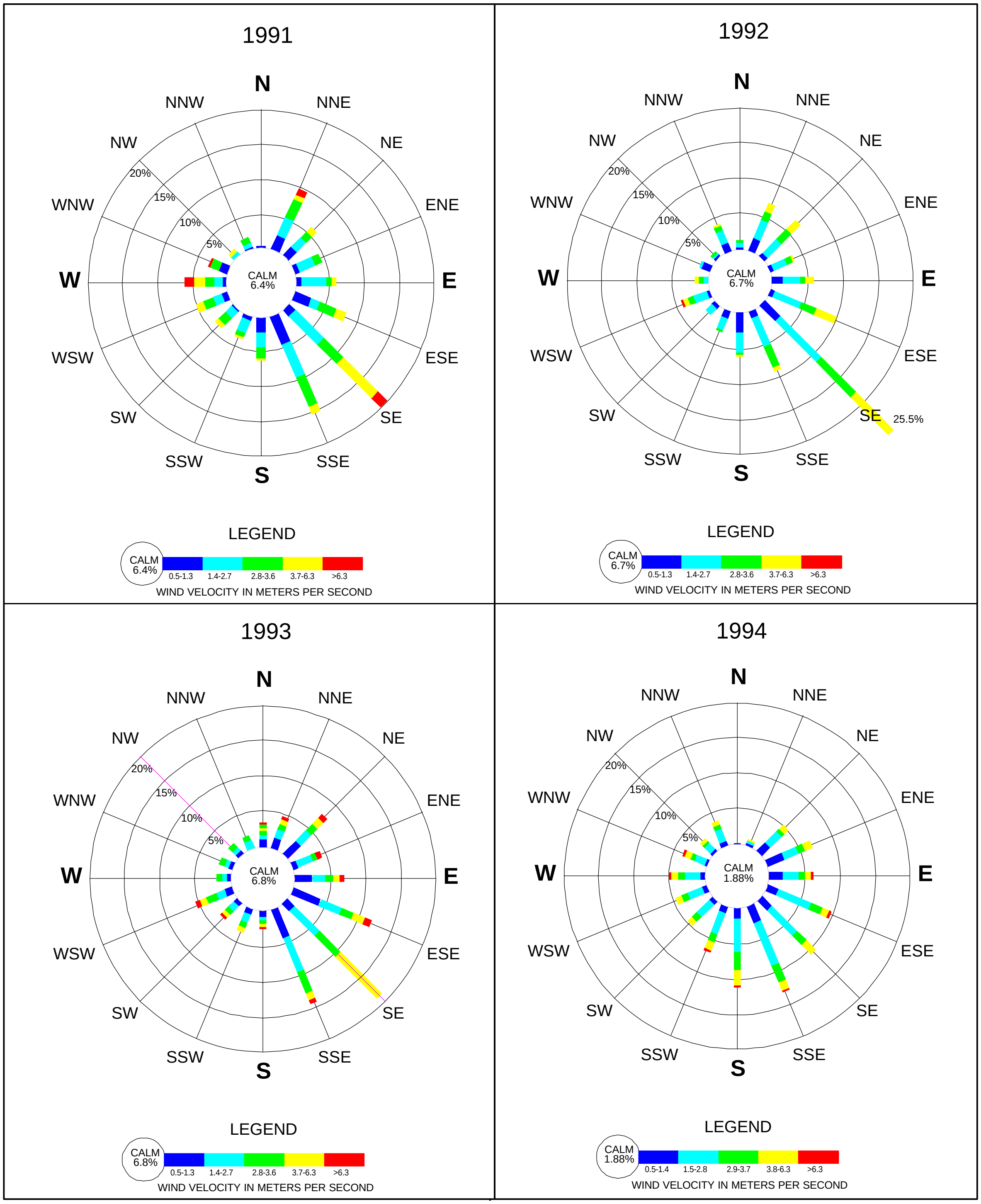
In 1991, after the EPA determined that air migration of VOCs would be a potential concern during testing at the facility, the VOC monitoring program was established at WIPP, and five VOC sampling stations were installed. The VOC monitoring program consisted of monitoring the air pulled from the exhaust shaft for any VOCs released from the test wastes. Samples were regularly analyzed for five target VOCs (carbon tetrachloride, methylene chloride, trichloroethylene, trichloroethane, and freon-113), and for other organics that might be detected.

Background monitoring of target VOCs will continue at three of the five locations. One location will measure the target compounds in the exhaust stream near the top of the exhaust shaft, another will sample the ambient air drawn into the underground facility, and the third will measure the background concentration. By measuring VOCs at the three locations it will be possible to define the variability in VOC concentration due to WIPP operations.

The regional climate is semiarid, with low precipitation and humidity and a high rate of evaporation. Precipitation is unevenly distributed throughout the year, with most occurring during summer thunderstorms. Winds are mostly from the southeast and moderate. In late winter and spring, there are strong west winds and dust storms. Thunderstorms are frequent from June through September, and are often accompanied by hail. Rains are brief but occasionally intense and can result in flash flooding in arroyos and along floodplains. Tornadoes are common throughout the region. From 1955 through 1967, 15 tornadoes were reported in the WIPP site area covered by one degree of latitude and longitude (DOE 1980).

The Carlsbad Air Terminal is the closest meteorological monitoring station and is located approximately 50 kilometers (30 miles) west of WIPP. Because of the relatively flat terrain, meteorological measurements at the airport are considered to be representative of the region. The mean annual temperature is 16 degrees Celsius (60 degrees Fahrenheit), and the mean annual precipitation is about 33 centimeters (13 inches). Drought conditions occurred during 1994. Precipitation for the 1994 calendar year was 31 percent less than that of the 1993 calendar year and 74 percent less than that of the 1992 calendar year.

The predominant wind direction at WIPP during calendar years 1991 through 1993 was from the southeast. However, during the 1994 calendar year, winds during late spring were primarily from the west. Wind speeds categorized as calm (less than 0.5 meters [1.6 feet] per second) usually occur about 7 percent of the time. Wind speeds of 1.4 through 2.7 meters (4.6 through 8.9 feet) per second were the most prevalent in the 1994 calendar year, occurring 25.5 percent of the time. Figure 4-3 displays the 1991 through 1994 wind roses (DOE 1992, 1993b, 1994a, and 1995d).



Source: DOE 1992, 1993b, 1994a, and 1995d

Figure 4-3
Windroses for 1991-1994

These conditions are consistent with long-term averages for the region. For a comprehensive discussion of climatology at the WIPP site, see Section 7.1.1 of the FEIS (DOE 1980). The WIPP site annual environmental reports (DOE 1991, 1992, 1993b, 1994a, 1995d, and 1996d) provide monthly and annual temperatures, precipitation, and wind conditions.

The ambient noise level in the WIPP area prior to construction was 26 to 28 decibels (DOE 1980). DOE requires its facilities to comply with Occupation Safety and Health Administration standards as promulgated in Title 29, of the Code of Federal Regulations (CFR), Section 1910.95. Any WIPP noise sources with the potential to exceed these standards have been mitigated (for example, noise dampers have been installed in the underground air exhausts) and are now in compliance with 29 CFR Section 1910.95.

KEY ELEMENTS CONCERNING GEOLOGY AND HYDROLOGY

Since publication of SEIS-I, additional studies and analyses have provided new information regarding geology and hydrology. These studies have improved the understanding of processes considered in evaluating long-term performance. Several examples are listed below:

- Extensive testing of the Salado Formation's salt beds and interbeds has resulted in confirmation of the Salado's extremely low permeability.
- Recent test data have enabled improved predictions of pressures at which Salado interbeds will likely fracture and relieve elevated gas pressures within the repository.
- Refined modeling of gas generation suggests that elevated gas pressure may slow down or stop brine inflow, thereby slowing gas-generating processes.
- Three-dimensional modeling of groundwater flow in the Rustler Formation suggests a very small amount of vertical flow and a preponderance of horizontal flow within the Culebra Dolomite.
- Recent tests on the Culebra Dolomite have provided new data on contaminant transport in the Culebra and on the Culebra's potential to retard radionuclides.

4.1.3 Geology and Hydrology

The first part of this section summarizes the geological and hydrological features of the WIPP site as well as key factors relevant to the repository's ability to isolate waste (repository performance). The remainder provides a discussion of what has been learned since SEIS-I. For the interested reader, there are several WIPP documents containing detailed, comprehensive, and technical descriptions of WIPP geology and hydrology. These documents have been incorporated by reference. Among them are FEIS (DOE 1980), SEIS-I (DOE 1990), the *Preliminary Performance Assessment for the Waste Isolation Pilot Plant* done by Sandia National Laboratories (SNL) (SNL 1992), the *Final No-Migration Variance Petition* (DOE 1996a), the *Waste Isolation Pilot Plant Safety Analysis Report* (DOE 1997a), and the *Title 40 CFR 191 Compliance Certification Application for the Waste Isolation Pilot Plant* (DOE 1996c). These references are cited throughout this section.

The geophysical, geochemical, and hydrological behavior of various strata believed to be important to WIPP performance has been investigated during almost 20 years as a part of the WIPP program. Since SEIS-I, most of the research performed has centered on improving understanding of groundwater flow and transport processes. This research has primarily dealt with: (1) hydraulic testing of the Salado Formation and characterization of brine flow within the Salado; (2) modeling of the interactions among gas generation, brine flow into the repository, and contaminated brine flow out of the repository; (3) modeling of regional groundwater flow in units above and below the Salado, particularly the Rustler Formation, which overlies the Salado and includes the Culebra

Dolomite; (4) hydraulic testing and tracer testing within the Culebra Dolomite; (5) characterization and modeling of hydrologic and geochemical characteristics of the Culebra; and (6) geophysical characterization of the pressurized brine occurrences in the Castile Formation that underlies the Salado. The following section summarizes results of investigations of WIPP geology and hydrology published since SEIS-I.

4.1.3.1 Geology

No substantive changes have occurred in the understanding of the site and regional geology since SEIS-I. A brief description of surface and subsurface geology and seismicity, both at the WIPP site and the region immediately surrounding the WIPP repository, is presented here. For detailed descriptions, see the references listed above.

Regional Setting and Surface Geology

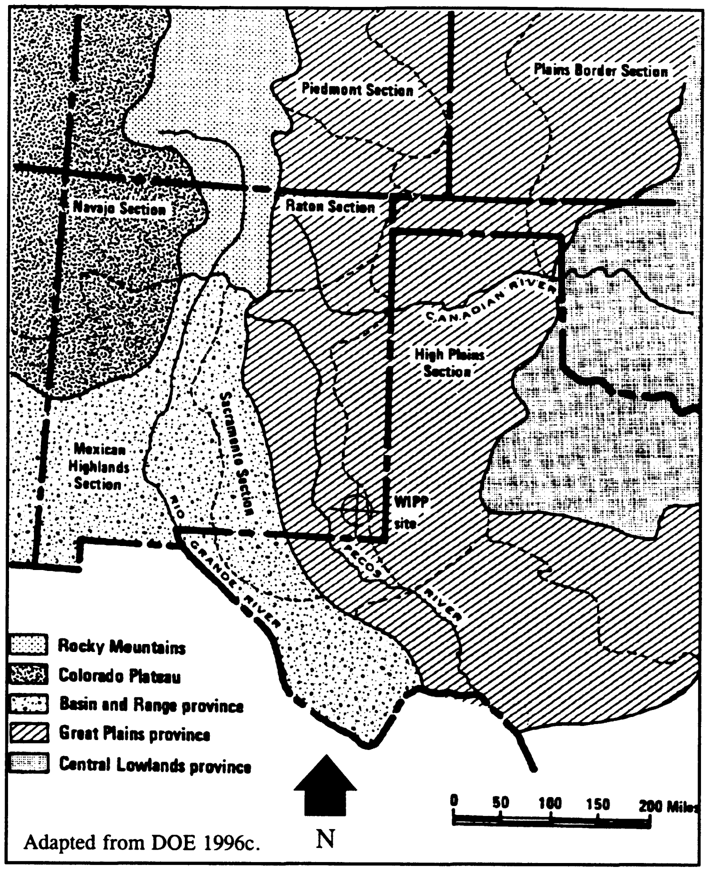
WIPP is located in southeastern New Mexico, in the Pecos Valley Section of the Great Plains Physiographic Province. The terrain throughout the province varies from plains and lowlands to rugged canyons. In the immediate vicinity of WIPP, numerous small mounds formed by wind-blown sand characterize the land surface. A layer enriched in calcium carbonate material, the Mescalero caliche, is typically present beneath the surface layer of sand. This caliche ranges in age from about 510,000 years at the base of the layer to about 410,000 years in the upper part, based on samples within the layer (DOE 1996c, Section 2.1). The caliche layer overlies a 600,000-year old volcanic ash layer (DOE 1996c, Section 2.1). The Mescalero caliche can be found over large portions of the Pecos River drainage area and is generally considered to be an indicator of surface stability (DOE 1980). The site slopes gently from east to west, from an elevation of 1,088 meters (3,570 feet) above sea level at its eastern boundary to 990 meters (3,250 feet) above sea level along its western boundary.

A high plains desert environment characterizes the area. Due to the seasonal nature of the rainfall, most surface drainage is intermittent. The Pecos River, 20 kilometers (12 miles) southwest of the WIPP boundary, is a perennial river and the master drainage for the region. A natural divide lies between the Pecos River and WIPP. As a result, the Pecos drainage system does not currently affect the site. Local physiographic features include Nash Draw and the San Simon Swale (see Figure 4-4).

Subsurface Geology

WIPP is located in the northern portion of the Delaware Basin, a structural basin underlying present-day southeastern New Mexico and western Texas and containing a thick sequence of sandstones, shales, carbonates, and evaporites. The references listed above describe basic characteristics of the stratigraphy (sequence of rock units) of the Delaware Basin.

The WIPP repository is located at a depth of approximately 655 meters (2,150 feet) in rocks of Permian age. The sediments accumulated during the Permian period represent the thickest portion of the sequence in the northern Delaware Basin and are divided into four series. From oldest to youngest, these series are: the Wolfcampian, Leonardian, Guadalupian, and Ochoan. As shown in Figure 4-5, the Ochoan series is divided into four formations. From oldest to youngest, these formations are: Castile, Salado (the lower part of which contains the WIPP repository), Rustler, and Dewey Lake.



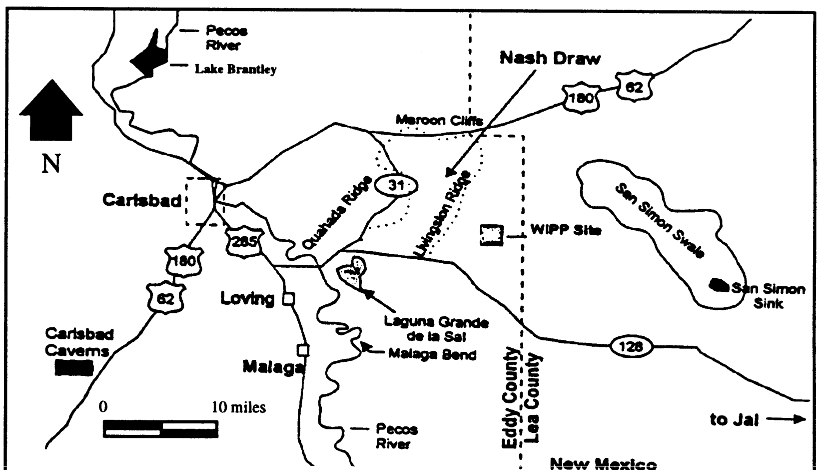


Figure 4-4
WIPP Site Location in Southeastern New Mexico

SYSTEM	SERIES	GROUP	FORMATION	MEMBER	DEPTH AT WIPP WASTE SHAFT meters (feet)
RECENT	RECENT		SURFICIAL DEPOSITS		
QUATER-NARY	PLEISTO-CENE		MESCALERO CALICHE		
			GATUNA		
TRIASSIC		DOCKUM	SANTA ROSA		30 (97)
PERMIAN	OCHOAN		DEWEY LAKE		164 (538)
			RUSTLER	Forty-niner	182 (596)
				Magenta Dolomite	189 (621)
				Tamarisk	215 (707)
				Culebra Dolomite	222 (729)
				lower unnamed	257 (844)
			SALADO	upper	409 (1,343)
				McNutt Potash	526 (1,727)
				lower WIPP	655 (2,150) ~810 (2,650)
			CASTILE		~1,200 (4,000)
	GUADALUPIAN	DELAWARE MOUNTAIN	BELL CANYON		~1,550 (5,100)
			CHERRY CANYON		~1,900 (6,200)
			BRUSHY CANYON		

Figure 4-5
Regional Geologic Column

The discussion below presents the geologic formations important to understanding the long-term performance of WIPP, including: the host rock for the WIPP repository (the Salado Formation), the formations below the Salado (the Castile and Bell Canyon Formations), and the formations above the Salado (the Rustler and Dewey Lake Formations).

Salado Formation

The Salado Formation is a massive bedded salt formation, predominantly halite (sodium chloride), and is thick and laterally extensive. DOE selected the Salado Formation as the site of the WIPP repository for several geologic reasons (DOE 1980, 1990): (1) the Salado halite units have very low permeability to fluid flow, which impedes groundwater flow into and out of the repository; (2) the Salado is regionally widespread; (3) the Salado includes continuous halite beds without complicated structure; (4) the Salado is deep with little potential for dissolution; (5) the Salado is near enough to the surface that access is reasonable; and (6) the Salado is largely free of mobile groundwater, as compared to existing mines and other potential repository sites.

The Salado Formation is approximately 530 to 610 meters (1,740 to 2,000 feet) thick in the WIPP site area, and the repository is located in the thickest part. The Salado is comprised of three members. From oldest to youngest, these are: the Lower Member, the McNutt Potash Member, and the Upper Member. The WIPP repository is located in the Lower Member. The Salado contains many distinctive and laterally continuous layers composed mostly of anhydrite (a calcium sulfate mineral) and polyhalite (a potassium-magnesium-calcium sulfate mineral). These layers are so continuous that they have been used by geologists as “marker beds” (MB) and numbered to designate vertical position within the Salado Formation. The WIPP repository is located between MB 139 and MB 138.

Castile Formation

The Castile Formation directly underlies the Salado Formation and comprises the base of the Ochoan Series (see Figure 4-5). It is found 244 meters (800 feet) below the level of the repository. The Castile Formation near WIPP typically contains three relatively thick anhydrite/carbonate units and two thick halite units. The thickness of the Castile varies regionally as well as locally beneath WIPP, and there is considerable evidence from borehole data and geophysical surveys that the units of the Castile are deformed. The more brittle anhydrite units of the Castile are probably fractured, and the fracture zones are relatively permeable and act as zones for accumulation of brine originating in the Castile (DOE 1997a). The Castile is exposed at the surface over a considerable area along the western side of the Delaware Basin. In the eastern part of the basin, it is approximately 430 to 460 meters (1,400 to 1,500 feet) thick. At the northern boundary of WIPP, the Castile’s thickness has been measured at 301 meters (989 feet).

Bell Canyon Formation

The Bell Canyon Formation underlies the Castile Formation and is the uppermost formation of the Guadalupian Series (see Figure 4-5). Near WIPP, the Bell Canyon is comprised of a layered sequence of sandstones, shales, siltstones, and limestones approximately 300 meters (1,000 feet) or more in thickness. It is the uppermost target of hydrocarbon exploration in the local area and is known from outcrops on the west side of the Delaware Basin and from oil and gas exploration boreholes (DOE 1996c, Section 2.1).

Rustler Formation

The Rustler Formation directly overlies the Salado Formation and contains five members (see Figure 4-5). From the base of the Rustler, these members are: the Unnamed lower member, the Culebra Dolomite, the Tamarisk, the Magenta Dolomite, and the Forty-niner. The Culebra and Magenta Dolomites are gypsum-bearing dolomites containing numerous cavities (vugs), fractures, and silty zones. The other three members contain various amounts of anhydrite, siltstone, claystone, and halite. The Rustler is the youngest (uppermost) formation in the Delaware Basin and primarily contains evaporite deposits. In the WIPP region, the Rustler can be 152 meters (500 feet) thick, although it ranges from 91 to 107 meters (300 to 350 feet) thick within the WIPP boundary.

Dewey Lake Formation

The Dewey Lake Formation overlies the Rustler Formation at WIPP (see Figure 4-5). Consisting largely of reddish-brown siltstones and claystones with lesser amounts of sandstone, the Dewey Lake Formation is about 30 to 170 meters (100 to 560 feet) thick in the vicinity of WIPP.

Santa Rosa Formation

The Santa Rosa Formation, also called the Dockum Group, overlies the Dewey Lake Formation. Characterized by light reddish-brown sandstones and conglomerates, the Santa Rosa Formation is thin to absent within the WIPP site boundaries, but is thicker (78 meters [255 feet] or greater) to the east (DOE 1996c, Section 2.1).

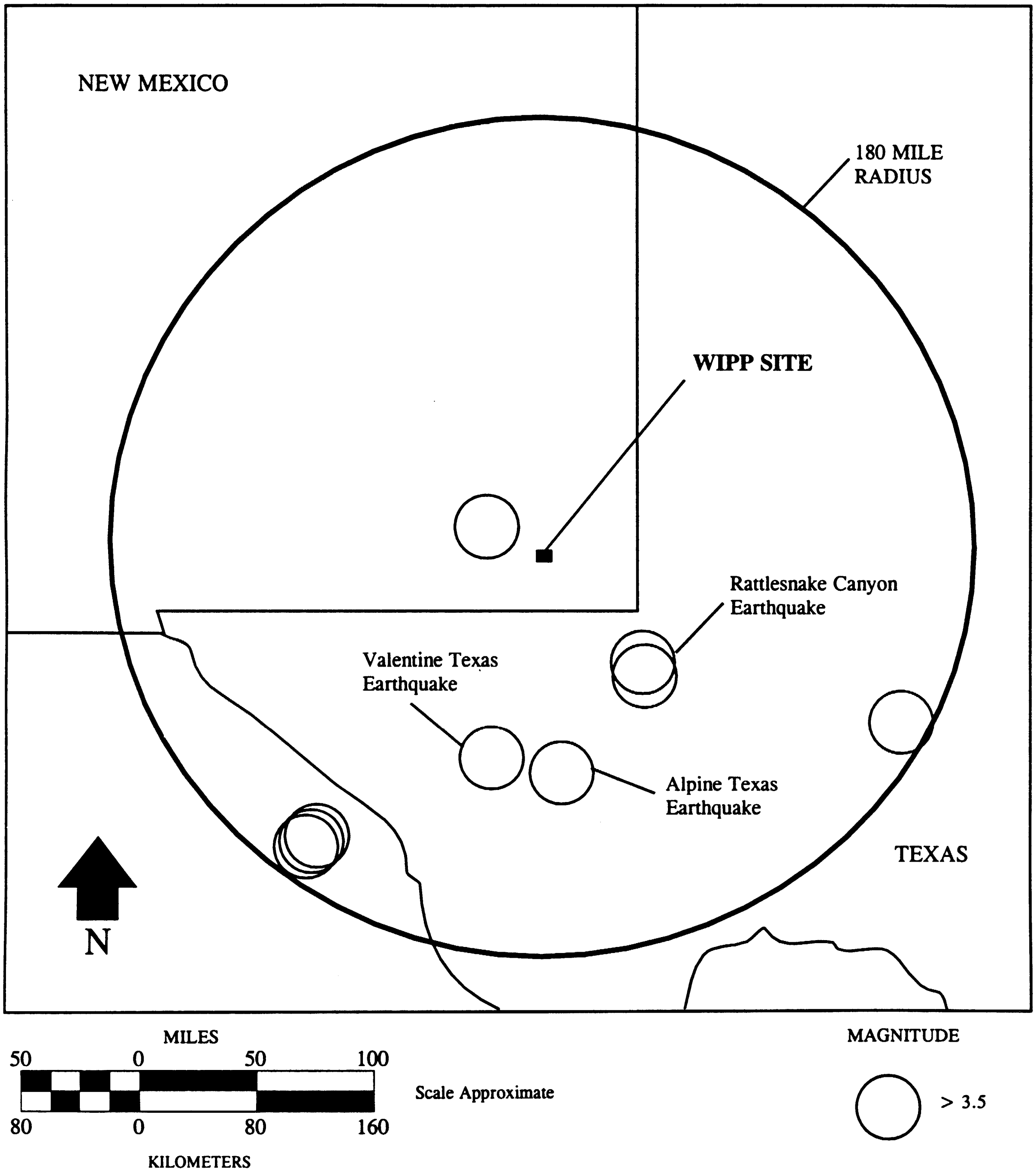
Gatuña Formation

The Gatuña Formation overlies the Santa Rosa Formation and is somewhat similar in lithology and color, although the Gatuña is characterized by a wide range of lithologies (coarse conglomerates to gypsum-bearing claystones). The Gatuña is Pleistocene in age, based on the 600,000-year old volcanic ash layer in the Upper Gatuña (DOE 1996c, Section 2.1). This is the same ash layer used to determine the upper age limit of the Mescalero Caliche that overlies the Gatuña Formation.

Faulting and Seismicity

Understanding of the regional seismicity has changed little since SEIS-I. No surface displacement or faulting younger than early Permian (Wolfcampian) has been reported, indicating that tectonic movement since then, if any, has not been noteworthy. No mapped Quaternary (last 1.9 million years) or Holocene (last 10,000 years) faults exist closer to the site than the western escarpment of the Guadalupe Mountains, about 100 kilometers (60 miles) west-southwest (DOE 1997a).

The strongest earthquake on record within 290 kilometers (180 miles) of the site was the Valentine, Texas, earthquake of August 16, 1931 (DOE 1997a), with an estimated Richter magnitude of 6.4. A Modified Mercalli Intensity V was estimated for this earthquake's groundshaking at WIPP. At Intensity V, groundshaking is felt by nearly everyone, a few instances of cracked plaster occur, and unstable objects are overturned. This is the strongest groundshaking intensity known for the WIPP site. This and other regional earthquakes are shown on Figure 4-6.



NOTES:

LOCATIONS OF SELECTED EARTHQUAKES WITHIN 300 KILOMETERS (180 MILES) OF THE WIPP SITE. FOR DRAFTING CLARITY NO EARTHQUAKE WITH A MAGNITUDE LESS THAN 3.5 IS SHOWN.

Figure 4-6
Regional Earthquake Epicenters Occurring after 1962

Since 1990, at least two seismic events have occurred that were recorded at WIPP. The Rattlesnake Canyon Earthquake occurred approximately 100 kilometers (60 miles) east-southeast of WIPP in January 1992. This event was assigned a Richter magnitude of 5.0 and occurred at a depth of approximately 12 kilometers (7.4 miles). This event had no effect on any of the structures at WIPP, as documented by post-event inspections by WIPP staff and the New Mexico Environment Department (DOE 1997a).

The most recent earthquake recorded at the WIPP site occurred on April 14, 1995, and was located 32 kilometers (20 miles) east-southeast of Alpine, Texas (approximately 240 kilometers [150 miles] south of the site). It was assigned a magnitude of 5.3 and is the largest event within 300 kilometers (185 miles) of the site since the Valentine, Texas, earthquake (Sanford et al. 1995). This event also had no effect on any structures at WIPP.

Based on a probabilistic seismic risk analysis and the region's historic seismicity, the strongest earthquake acceleration expected at WIPP would be 0.075 gravity (7.5 percent of acceleration due to gravity) with an average return period of 1,000 years. The design-basis earthquake (DBE) is conservatively assumed to be 0.1 gravity. Mine experience and studies on earthquake damage to underground facilities show that tunnels, mines, and wells are not damaged at sites having peak surface accelerations below 0.2 gravity (DOE 1997a).

Natural Resource Exploration and Development

Hydrocarbons

Prior to 1970, most commercially related drilling in the WIPP area targeted shallow oil (1,200 to 1,400 meters [4,000 to 4,500 feet] in depth) in the Bell Canyon Formation. Most of the exploratory wells from this period were plugged and abandoned. From 1970 to the mid-1980s, most drilling near WIPP focused on gas exploration in the deeper Morrow and Atoka Formations (approximately 4,000 meters [13,000 feet]). Most drilling for deep gas occurred northeast of WIPP. After parts of the Potash Area were opened to oil and gas exploration in the 1990s, exploration for deep gas in the Morrow and Atoka Formations occurred along the western boundary of the WIPP land withdrawal area (Broadhead et al. 1995).

According to Broadhead et al. (1995), estimates of probable oil and condensate resources within the WIPP Land Withdrawal Area include 12.3 million barrels of oil and gas condensate recoverable by primary production methods and an additional 6.4 million barrels of oil potentially recoverable by secondary recovery and waterfloods. Probable gas resources could total 5.3 billion cubic meters (186 billion cubic feet), 89 percent of which will be produced from the Atoka and Morrow Reservoirs. The remainder of the gas could be produced from shallow reservoirs in the Delaware Mountain Group. Probable resources within an additional 1.6-kilometer-wide (1-mile-wide) study area surrounding the withdrawn acreage include 22.9 million barrels of oil and gas condensate that could be recoverable by primary production methods and an additional 13.8 million barrels of oil that could be recoverable through waterflooding. Probable gas resources in this area could total 4.7 billion cubic meters (168 billion cubic feet), 79 percent of which could be produced from the deep Strawn, Atoka, and Morrow Reservoirs.

Broadhead et al. (1995) also state that possibly significant additional resources of oil, gas, and gas condensate exist beneath the WIPP site and the additional 1.6-kilometer-wide (1-mile-wide) area in untapped sandstones of the Delaware Mountain Group, in largely unexplored and unevaluated sandstones and carbonates of the Bone Spring Formation, and in carbonate reservoirs in the Wolfcamp and Strawn Group. During the late 1980s and early 1990s, commercial oil was discovered in the Cherry Canyon and Brushy Canyon Formations of the Delaware Mountain Group adjacent to the eastern and northeastern boundary of WIPP, at a depth of approximately 2,100 to 2,400 meters (7,000 to 8,000 feet). These formations are currently the primary exploration and development targets in the Permian Basin, one of the most actively explored areas in the United States (Broadhead et al. 1995).

According to a study of comprehensive well records for nine townships around the WIPP site (Broadhead et al. 1995), 532 wells had been drilled in search of oil and gas by the end of 1993 (Figure 4-7). Few wells had been drilled in the area prior to 1960. Between 1960 and 1989, drilling activity increased but was sporadic and never exceeded 20 wells per year. Since 1990, however, drilling has increased markedly, with annual totals increasing to a maximum of 140 wells in 1993 (Figure 4-8). This increase has been partially attributable to the opening of previously restricted areas of the Potash Area to drilling. Most of these wells were drilled into the Brushy Canyon Formation of the Delaware Mountain Group.

Three commercial wells have been drilled for oil and gas within the boundaries of the WIPP Land Withdrawal Area (see Figure 4-7). Two vertical wells were drilled within the area during the 1970s; neither one became a producing well. A third well was drilled in 1982 from a location outside of the WIPP Land Withdrawal Area. The well was drilled at an angle underneath the area to intercept gas in the Atoka Formation and is currently commercially productive (Broadhead et al. 1995).

Potash

Bedded potash was discovered in Eddy County, New Mexico, in 1925. By 1944, New Mexico was the largest domestic potash producer, representing 85 percent of consumption. Development continued through the 1950s and 1960s, reversed in the 1970s and, for several reasons has declined since (Barker and Austin 1995).

The Carlsbad Potash District, located in southeastern New Mexico near the northeastern border of the Delaware Basin, contains the largest domestic potash reserves. Sylvinite, a mixture of sylvite and halite, is the typical potash ore mined in the Carlsbad Potash District. The only potash mines in the state are located in Eddy and Lea Counties within the soluble potash zone. The WIPP Land Withdrawal Area occupies approximately 41 square kilometers (16 square miles) on the southeastern edge of the Known Potash Leasing Area (or Potash Enclave, administered by BLM) (see Figure 4-9). During the last decade or so, commercial potash mining has continued and the mining front is much closer to the WIPP site, having approached the site boundary on the southwestern side. Future mining is likely to occur there or on the north side of the site (Barker and Austin 1995).

Within the Known Potash Leasing Area, the majority of actively mined and potential resources of potash ore are found in the 37-meter-thick (120-foot-thick) McNutt Member of the Salado Formation, which is the host for 11 ore zones. Horizon Number 1 is at the base of the McNutt Member and Number 11, which is not mined, is at the top. In the vicinity of the withdrawal area, the McNutt Member is found at depths ranging from 400 to 525 meters (1,312 to 1,722 feet) above the repository horizon. An additional ore zone is found in the Upper Member of the Salado.

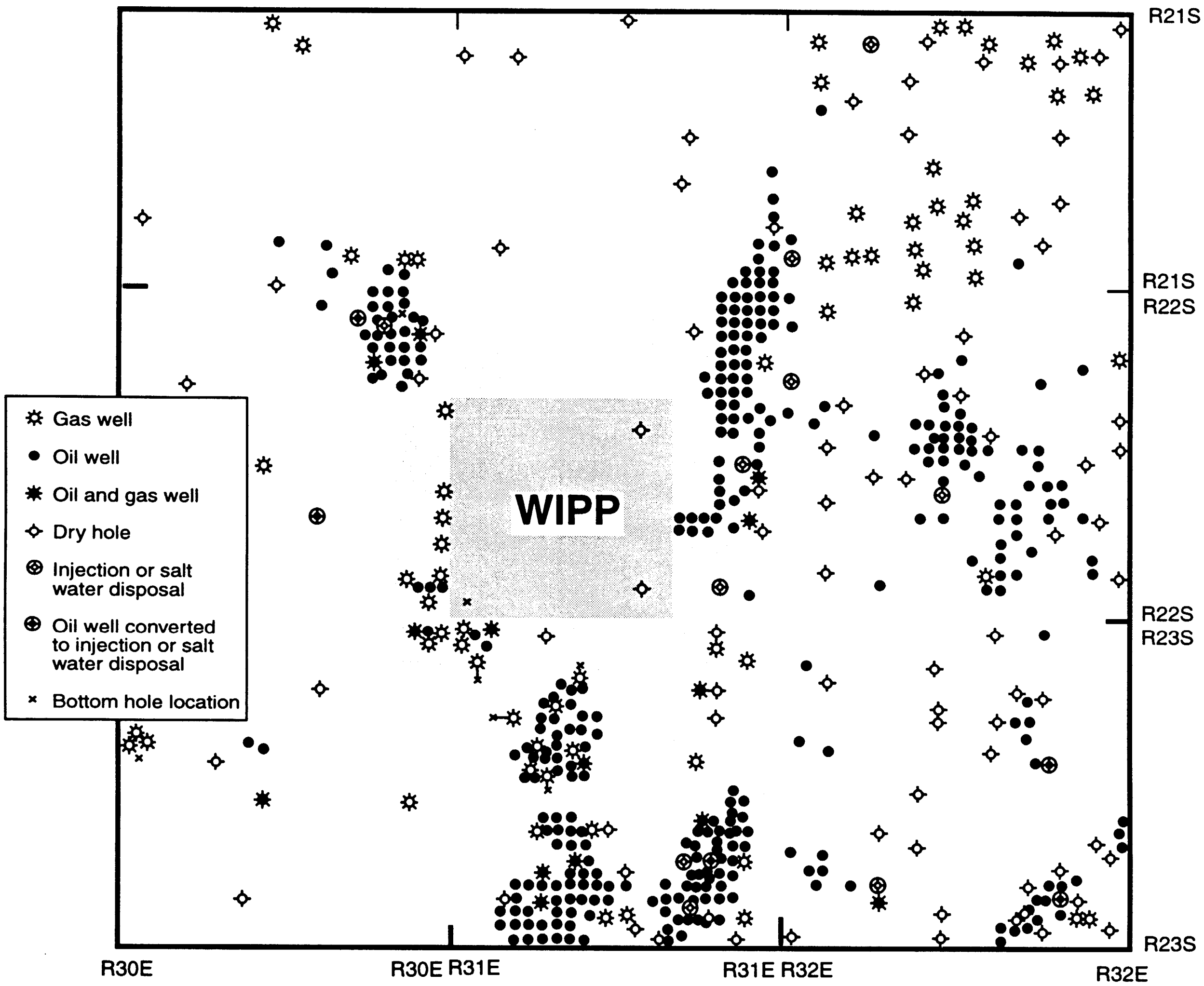


Figure 4-7
Oil, Gas, and Injection Wells in the Nine-Township Area Centered on the WIPP Site

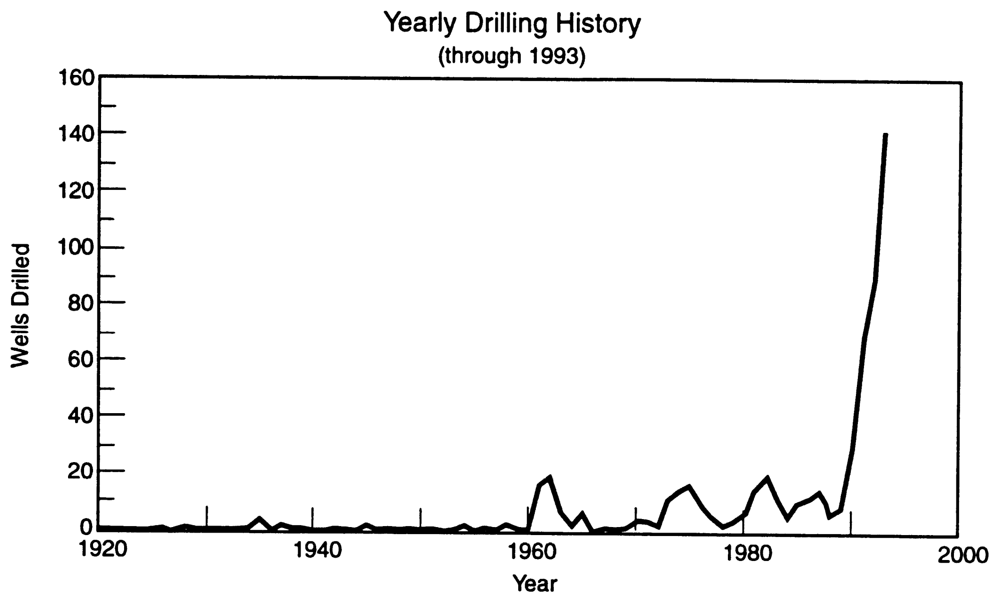


Figure 4-8
Annual Number of Oil and Gas Wells Completed in the Nine-Township Area Centered on the WIPP Site

Potash ore zones are 1 to 3 meters (3 to 10 feet) thick and are laterally consistent except where interrupted by salt horses, collapse features, and igneous dikes (Barker and Austin 1995). Continuous mining equipment that has been adapted from coal mining is used to extract most of the potash ore, although blasting is also used. All mines in the Carlsbad Potash District consist of at least two shafts for safety and ventilation, and older mines may have three or more shafts because working faces are now 5 to 8 kilometers (3 to 5 miles) from the main shafts.

A summary of the current knowledge and estimates of potash mining reserves, based on recent work performed by the New Mexico Bureau of Mines and Mineral Resources in the vicinity of the WIPP site, is provided in Attachment 15-5 of Appendix MASS of the *Title 40 CFR 191 Compliance Certification Application for the Waste Isolation Pilot Plant* (CCA) (DOE 1996c). A summary of current leases indicates that all are held by eight holding companies, five of which are actively mining in the area. No active potash mining leases currently exist within the WIPP controlled area.

4.1.3.2 Hydrology

This section provides a summary of the surface hydrology of the WIPP region, followed by the hydraulic and hydrogeologic characteristics of the geologic formations relevant to WIPP.

Surface Water Hydrology

Understanding of the surface water hydrology in the WIPP vicinity has changed little since SEIS-I. WIPP is located east of the Pecos River and within the Pecos River basin (which represents about one-half of the drainage area of the Rio Grande Water Resources Region). The drainage area of

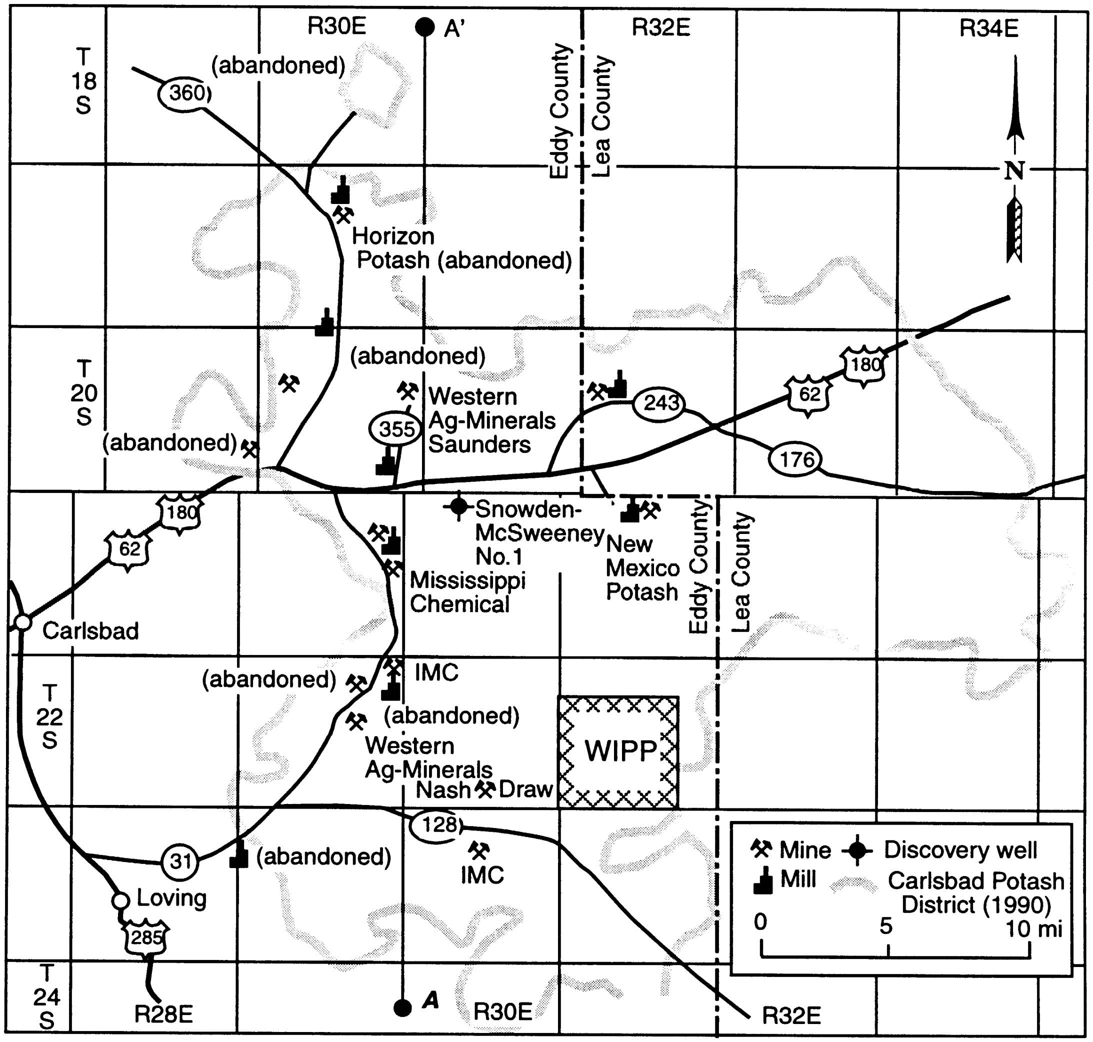


Figure 4-9
Active, Inactive, and Abandoned Potash Facilities in Eddy and Lea Counties, Southeastern New Mexico, Within the Carlsbad Potash District

the Pecos River at this location is 49,200 square kilometers (19,000 square miles). The WIPP site has a few small intermittent creeks, the only westward-flowing tributaries of the Pecos River within 32 kilometers (20 miles) north or south of the site.

The Pecos River is the main surface water resource in the WIPP vicinity. Due to inflow from brine springs (from the Rustler Formation) and slight exceedence of water quality levels of certain heavy metals (DOE 1996a), river water is not used for human consumption. Irrigation and livestock watering are the primary uses of the water from the Pecos.

More than 90 percent of the mean annual precipitation at the site is lost by evapotranspiration. On a mean monthly basis, evapotranspiration at the site greatly exceeds the available rainfall; however, intense local thunderstorms produce runoff and percolation. The maximum recorded flood on the Pecos River occurred on August 23, 1966, near Malaga, about 25 kilometers (15 miles) from WIPP. The maximum elevation of the flood was 90 meters (300 feet) below the elevation of the WIPP surface facility.

Groundwater Hydrology

The WIPP repository is situated in the thick, relatively impermeable Salado Formation salt beds 655 meters (2,150 feet) below the ground surface. The hydrologic and mechanical properties of the salt beds surrounding WIPP are better understood than the regional hydrology. Generally, however, groundwater in the Rustler and Dewey Lake Formations and the units overlying them are essentially isolated from the hydrology of the Salado Formation.

The Rustler Formation includes the Culebra and Magenta Dolomites, two units containing water of low quality (brine to brackish) (DOE 1996c, Section 2.2.1). The Culebra Dolomite, which is the first notable water-bearing unit above the Salado Formation, has been investigated for its potential to transport radionuclides released from the repository resulting from a borehole intrusion. Groundwater flow in the units overlying the Salado Formation has been assumed to occur primarily in the Culebra Dolomite, although it is recognized that regional flow in the Rustler Formation is three-dimensional and occurs to some degree in all Rustler units (DOE 1996c, Section 2.2.1). Flow in the Culebra is generally from north to south. The Dewey Lake Formation overlies the Rustler Formation and in some areas is relatively transmissive, particularly in the south central and southwestern part of the WIPP site (DOE 1996c, Section 2.2.1). The location of the water table is generally considered to be the Dewey Lake.

Only a few locations of groundwater recharge and discharge to and from the Rustler Formation are known. The only documented areas of naturally occurring groundwater discharge in the vicinity of WIPP are the Pecos River near Malaga Bend (Hunter 1985) and, to a lesser extent, the saline lakes in Nash Draw. This local flow associated with Nash Draw is unrelated to groundwater flow at WIPP. The only documented area of groundwater recharge is also near Malaga Bend (Hunter 1985). This location is hydraulically downgradient from the repository, and recharge here has little relevance to flow near WIPP. Recent regional groundwater modeling by Corbet and Knupp (1996) has suggested that groundwater in the Culebra, Magenta, and Dewey Lake and Triassic units originates in areas that are north and northeast of the WIPP site (DOE 1996c).

The following sections discuss the hydraulic and hydrogeologic characteristics of the geologic formations enclosing, underlying, and overlying the WIPP underground facility.

Salado Formation Hydrology

As described above, the Salado Formation has several characteristics which make it a favorable host medium for a repository, including its low permeability to fluids and its relatively low water content. Hydraulic tests from which permeabilities have been derived indicate that the Salado halite has either extremely low or no permeability (no measurable flow occurred during some of the tests). Tests in pure halite indicate permeabilities of less than 1×10^{-23} square meters (1×10^{-22} square feet); permeabilities measured in impure halite range from 1×10^{-23} to 4×10^{-18} square meters (1×10^{-22} to 4×10^{-17} square feet) (DOE 1996c, Section 2.2.1).

There is also indirect evidence of the Salado's low permeability. Measurements in the Salado in the WIPP site region have shown that there are areas of anomalously high and low fluid pressures. If the Salado were relatively permeable, these pressures would likely have equalized relatively quickly; conversely, if the Salado were relatively impermeable, these pressures would probably not equalize, or would do so only over a very long time. Since these pressure differences do exist, it is likely that these areas of anomalous pressures have remained constant over long periods of time because of the relative lack of permeability of the salt (Lappin et al. 1989).

Inflow of brine into the repository excavation has been observed in boreholes and from "weeps," which are localized brine seeps issuing from cracks in the disturbed surfaces of the repository walls, floors, and roofs. The volumes of brine observed from these occurrences have been small, and flow into the repository has ceased within three years of initial observation (DOE 1996c, Appendix MASS). Brine migrates along clay-rich layers and cracks developed in the "disturbed rock zone" (DRZ). Eventually the DRZ heals, thereby cutting off fracture-controlled flow paths into the repository. Nevertheless, for the long-term, it is reasonable and conservative to consider that there may be brine near the repository that would flow toward and into the repository, albeit at a low rate.

Models are available to estimate the amount of brine that would flow into the excavation over time. DOE (1996c) discussed three mechanisms of brine inflow: (1) far-field flow, which is flow from outside the influence of the repository along naturally interconnected pore spaces; (2) redistribution, which is flow within the interconnected fractures of the DRZ; and (3) clay consolidation, which is the squeezing of water out of clay layers which intersect the repository. Of these mechanisms, only the first two are considered crucial (DOE 1996c, Appendix MASS); together, they are capable of contributing approximately 50 to 160 cubic meters (1,785 to 5,712 cubic feet) of brine per disposal room, which has an approximate volume of 3,675 cubic meters (128,700 cubic feet) (DOE 1996c, Appendix MASS).

Brine inflow is a concern in that the brine would provide necessary moisture for the degradation of certain waste material components and gas generation. This could occur from a combination of processes such as microbial activity, canister corrosion, corrosion of metal waste, and radiolysis of brine. If a sufficient supply of brine exists and gas accumulates faster than it can dissipate, it is conceivable that gas pressure could build up to the point that it exceeds lithostatic pressure (approximately 15 million pascals). In this event, fractures would form in the repository walls and provide pathways for contaminants away from the repository.

According to the CCA (DOE 1996c), the total volume of gas that may be generated by corrosion and microbial degradation may be sufficient to result in repository pressures that approach lithostatic levels. Sustained pressures above lithostatic levels are not physically reasonable within the disposal system, and fracturing of the more brittle anhydrite layers is expected to occur if sufficient gas is present. The permeability and porosity of the anhydrite marker beds (MB 138 and MB 139) will increase rapidly as pore pressure approaches and exceeds lithostatic levels. Pressure-dependent fracturing approximates the hydraulic effect of pressure-induced fracturing and will likely allow gas and brine to move more freely within the marker beds at higher pressures. The interbeds may be expected to serve as conduits for brine flow between the impure halite and the repository. Conceptually, brine flows laterally along higher permeability interbeds toward or away from the repository and vertically between the interbeds and the lower permeability halite. Because the interbeds have a very large contact area with adjacent halite-rich rock, even a very small flux from the halite into the interbeds (for brine inflow) or to the halite from the interbeds (for brine outflow) can accumulate into a significant quantity of brine. In this manner, halite serves as a source or sink for brine in the repository. It is expected that, because of density differences between gas and brine and their stratification within the repository, brine outflow will be dominantly in MB 139, and gas outflow will occur in anhydrite a and b or MB 138.

Interbeds also contain natural fractures that may be partially healed. If high pressure is developed in an interbed, its preexisting fractures may dilate or new fractures may form, altering its porosity and permeability. Pressure-dependent changes in permeability are supported by experiments conducted in the WIPP underground and in the laboratory (Beauheim et al. 1993). To the extent that it occurs, dilation or fracturing of interbeds is expected to increase the transmissivity of interbed intervals. The threshold pressure of dilated or fractured interbeds is expected to be low because apertures of the fractures increase; thus, fluid is expected to be able to flow outward readily if adequate pressure is available to dilate the interbeds.

The Salado salt has such a low permeability that it is difficult to measure with existing technology. Studies of the Salado indicate that the impure halite (greater than 0.5 percent impurities) may exhibit brine flow through pore spaces and along grain boundaries, but measurements on continuous layers of pure halite indicate zero or near-zero permeabilities. The interpretation of flow mechanism is inconclusive. The presence of the pure halite layers suggests that vertical flow through the Salado does not occur (DOE 1996c, Section 2.2.1).

Castile Formation Hydrology

The Castile Formation is dominated by anhydrite and halite zones of low permeability (DOE 1996c, Section 2.2.1.2); however, fracturing in the anhydrite zone of the upper portion of the Castile has generated isolated regions with much greater permeability than the surrounding intact anhydrite. These regions, referred to as brine reservoirs, contain brine at greater than hydrostatic pressure.

Castile brine reservoirs in the northern Delaware Basin contain widely spaced, highly-angled fractures; therefore, a borehole which penetrated through a brine reservoir would be unlikely to intersect a fracture and release brine. Appreciable volumes of brine have been produced from several reservoirs in the Delaware Basin, but there is little direct information on the areal extent of the reservoirs or the interconnection between them (DOE 1996c, Section 2.2.1.2).

Borehole ERDA-6, located 5 kilometers (3 miles) northeast of the WIPP site, and borehole WIPP-12, 1.6 kilometers (1 mile) north of the site center, encountered a zone of pressurized brine within the Castile Formation (DOE 1996c, Section 2.2.1.2). The fluid pressure measured in 1983 in the WIPP-12 borehole was 12.7 megapascals, greater than the nominal hydrostatic pressure of 11.1 megapascals for a column of equivalent brine at that depth. Results of hydraulic tests performed in the ERDA-6 and WIPP-12 boreholes suggest that the extent of the highly permeable portions of the Castile is limited. The vast majority of brine is thought to be stored in low-permeability microfractures, with about 5 percent of the overall brine volume stored in large, open fractures. The volumes of the ERDA-6 and WIPP-12 brine reservoirs were estimated in 1983 to be 100,000 cubic meters (3.5×10^6 cubic feet) and 2.7 million cubic meters (9.5×10^7 cubic feet), respectively.

A geophysical survey using time-domain electromagnetic (TDEM) methods was completed over the WIPP-12 brine reservoir and the waste disposal panels (DOE 1996c, Section 2.2.1.2). The TDEM measurements detected a conductor thought to be the WIPP-12 brine reservoir and also indicated that similar brine reservoirs may be present within the Castile under a portion of the waste disposal panels. In a recent geostatistical analysis, 354 drill holes and 27 Castile brine occurrences were used to establish that there is an 8 percent probability that a hole drilled into the waste panel region would encounter brine in the Castile. This analysis is included in the CCA as Attachment 18-6 in Appendix MASS (DOE 1996c).

The origin of brine in the Castile has been investigated geochemically and reported in the CCA in Section 2.1.6.2 (DOE 1996c). Based on the ratios of major and minor element concentrations in the brine, the report concluded that these fluids originated from ancient seawater and that no evidence exists for fluid contribution from present meteoric waters. The Castile brine chemistries from the ERDA-6 and WIPP-12 reservoirs are distinctly different from each other and from local groundwater samples. The geochemical data indicate that the brine in reservoirs has not mixed to any significant extent with other bodies of water and has not circulated. The brine is saturated, or nearly so, with respect to halite and, consequently, has little potential to dissolve halite.

Bell Canyon Formation Hydrology

The Bell Canyon Formation is considered to form a single hydrostratigraphic unit about 300 meters (1,000 feet) thick. The low-permeability of the Castile Formation that overlies it effectively isolates the fluid flow in the Bell Canyon. In the WIPP vicinity, the brines in the Bell Canyon flow northeasterly and discharge into the Capitan aquifer (DOE 1996c, Section 2.2.1.2).

Rustler Formation Hydrology

The Rustler Formation is the most significant hydrogeologic unit above WIPP because it contains the Culebra Dolomite, the first laterally continuous hydrologic unit above the Salado Formation. In addition to the Culebra, the Rustler Formation also contains four other units: 1) the Unnamed Lower Member, 2) the Tamarisk Member, 3) the Magenta Dolomite Member, and 4) the Forty-Niner Member. The following summary of the most current understanding of all these units draws mainly from discussions in the CCA (DOE 1996c, Section 2.2.1.4).

Unnamed Lower Member

The Unnamed Lower Member makes up a single hydrostratigraphic unit in WIPP models of the Rustler Formation, although its composition varies somewhat (DOE 1996c, Section 2.2.1.4). Overall, it acts as a confining layer: the basal interval of the Unnamed Lower Member, approximately 19.5 meters (64 feet) thick, is composed of siltstone, mudstone, and claystone, and contains the water-producing zones of the lowermost Rustler. Transmissivity values of 2.9 x 10^{-10} square meters (3.12 x 10^{-9} square feet) per second and 2.4 x 10^{-10} square meters (2.58 x 10^{-9} square feet) per second were reported from tests at well H-16, corresponding to hydraulic conductivities of 1.5 x 10^{-11} meters (4.95 x 10^{-11} feet) per second and 1.2 x 10^{-11} meters (3.96 x 10^{-11} feet) per second. Hydraulic conductivity in the lower portion of the Unnamed Lower Member is believed by DOE to increase to the west in and near Nash Draw, where dissolution at the underlying Rustler-Salado contact has caused subsidence and fracturing of the sandstone and siltstone. The porosity of the Unnamed Lower Member was measured in 1995 as part of the H-19 hydropad testing. Two claystone samples had effective porosities of 26.8 and 27.3 percent, and one anhydrite sample had an effective porosity of 0.2 percent.

The remainder of the Unnamed Lower Member contains mudstones, anhydrite, and variable amounts of halite. The hydraulic conductivity of these lithologies is extremely low; tests of mudstones and claystones in the waste handling shaft gave hydraulic conductivity values varying from 6 x 10^{-15} meters (1.98 x 10^{-14} feet) per second to 1 x 10^{-13} meters (3.28 x 10^{-13} feet) per second (DOE 1996c, Section 2.2.1.4).

Culebra Member

The Culebra Member, also referred to as the Culebra Dolomite, has been the most investigated hydrogeologic unit in the Rustler Formation during the past decade since it is the most transmissive unit at the WIPP site. Because of its hydraulic characteristics, the Culebra is considered the most likely pathway for radionuclide releases from the repository to the accessible environment.

According to the CCA, Culebra flow patterns have been recognized as moving predominantly north to south on the WIPP site and strongly affected by a high transmissivity zone in the southeastern portion of the site. Contours of these water levels suggest that the flow above the WIPP repository is to the south, flow in Nash Draw is to the southwest, and flow south of WIPP is possibly toward the west.

In the past trends in water chemistry along the inferred southerly flow have been an issue in interpretations of local flow conditions in the Culebra Dolomite. Using generally accepted interpretations of flow and chemistry, total dissolved solids would be expected to decrease and the general character of groundwater would be expected to change in the principal direction of groundwater flow. A number of past interpretations of groundwater flow paths and solute chemistry of the Culebra were based on the concept that groundwater flow in the Culebra was a confined system and that rock interactions along the flow path from WIPP must transform the groundwater from a more saline sodium chloride-type water to a more dilute calcium sulfate-type water.

In a recent interpretation by Corbet (1997), the Department has suggested that changes in groundwater chemistry that would be expected for a confined system are complicated by contributions of vertical leakage and regional groundwater recharge that interact with distinctive rock types originating in different areas surrounding the WIPP site. Corbet (1997) concludes that the distributions of solute chemistry observed in the Culebra are consistent with inferred groundwater flow conditions and reflect with a mixing of distinctly different groundwater originating in recharge areas to the east (slowly moving saline groundwater originating from dissolution of the Rustler and/or Salado and moving to the west), southwest (groundwater reacting with anhydrites of the Rustler and flowing southeast), and north and northeast (meteoric recharge water reacting with Rustler anhydrites and moving south through the WIPP site).

Over the years, both hydraulic and tracer tests have been used to characterize the flow and transport characteristics of the Culebra. The Culebra is a fractured dolomite layer with properties that vary horizontally and vertically. Examination of core and shaft exposures has revealed that there are multiple scales of porosity within the Culebra, including fractures ranging from microscale to potentially large, vuggy (cavity-filled) zones, and interparticle and intercystalline porosity. Measurements of core samples indicate porosities ranging from 0.03 to 0.30 (DOE 1996c, Section 2.2.1.4); this large range in porosity for small samples is expected, given the variety of porosity types within the Culebra. The core measurements indicate that the Culebra has a significant number of porosity connections leading to a limited amount of fluid movement, particularly within interparticle cavities where the porosity and permeability is high, such as in chalky lenses.

The majority of fluid movement in the Culebra occurs within fractures and within vugs connected by fractures (DOE 1996c, Section 2.2.1.4). In some regions, the permeability of the fractures is inferred to be significantly higher than the permeability of the other porosity types; in other regions, there appear to be no fractures of high permeability, which may be due to a lack of large fractures or the result of gypsum fillings in portions of the Culebra.

The hydraulic tests have been designed to yield pressure data that can be used in the interpretation of Culebra transmissivity, permeability, and storativity. The most detailed hydraulic data have been collected from tests at the WIPP hydropads, which generally comprise a network of three or more wells located within close proximity of each other. Long-term pumping tests yielding pressure data over a large area have been conducted at hydropads H-3, H-11, and H-19, and at well WIPP-13. In addition, slug tests and short-term pumping tests conducted at individual wells have provided pressure data that can be used to interpret the transmissivity at those locations. Detailed cross-hole hydraulic tests that yielded data on hydraulic properties have recently been conducted at the H-19 hydropad. The pressure data from long-term pumping tests and the interpreted transmissivity values for individual wells are used to generate the transmissivity fields of the Culebra that were used in performance assessment flow modeling (see DOE 1996c, Appendix TFIELD).

In order to evaluate the transport properties of the Culebra Dolomite, a series of tracer tests was conducted at the H-2, H-3, H-4, H-6, H-11, and H-19 hydropads near the WIPP site. Tests at the first five locations consisted of two-well dipole tests and/or multi-well convergent flow tests and are described in detail in Jones et al. (1992). More recent tracer tests at the H-19 hydropad and additional tracer tests performed at the H-11 hydropad consisted of single-well injection-withdrawal tests and multi-well convergent flow tests and are described in the CCA (DOE 1996c, Section 2.2.1.4). The recent tracer tests were specifically designed to evaluate the importance of horizontal and vertical heterogeneity and diffusion on transport processes.

Tamarisk Member

The Tamarisk Member functions as a confining layer. Attempts were made in two wells, H-14 and H-16, to test a 2.4-meter (7.9-foot) sequence of the Tamarisk that consists of layers of claystone, mudstone, and siltstone sandwiched between layers of anhydrite. The permeability was too low to measure in either well within the time allowed for testing; consequently, the transmissivity of the claystone sequence was estimated to be less than approximately 2.7 x 10^{-11} square meters (2.9 x 10^{-10} square feet) per second, one or more orders of magnitude less than that of the tested interval in the Unnamed Lower Member. The porosity of the Tamarisk was measured in 1995 as part of testing at the H-19 hydropad. Two claystone samples had an effective porosity of 21.3 to 21.7 percent, and five anhydrite samples had effective porosities of 0.2 to 1.0 percent (DOE 1996c, Section 2.2.1.4).

Magenta Member

The Magenta Member is a conductive, hydrostratigraphic unit about 7.9 meters (26 feet) thick at WIPP. The Magenta is saturated except near outcrops along Nash Draw, and hydraulic data are available from 15 wells. Transmissivity ranges over five orders of magnitude from 1 x 10^{-9} to 4 x 10^{-4} square meters (1.08 x 10^{-8} to 4.30 x 10^{-3} square feet) per second. The porosity of the Magenta was measured in 1995 as part of testing at the H-19 hydropad. Four samples had effective porosities ranging from 2.7 to 25.2 percent (DOE 1996c, Appendix HYDRO).

The hydraulic transmissivities of the Magenta, based on sparse data, show a decrease in conductivity from west to east, with slight indentations of the contours north and south of WIPP that correspond to the topographic expression of Nash Draw. In most locations, the hydraulic conductivity of the Magenta is one to two orders of magnitude less than that of the Culebra. The Magenta does not have hydraulically significant fractures in the vicinity of WIPP. The hydraulic gradient across the site varies from 3 to 4 meters per kilometer (16 to 20 feet per mile) on the eastern side, steepening to about 6 meters per kilometer (32 feet per mile) along the western side near Nash Draw (DOE 1996c, Figure 2-32).

Inferences about vertical flow directions in the Magenta have been made from well data collected by DOE, which reported a downward flow out of the Magenta over the WIPP site, consistent with results of groundwater basin modeling. However, DOE concluded that flow between the Forty-Niner and Magenta would be upward in H-3, H-14, and H-16, three boreholes which yielded reliable pressure data for the Forty-Niner. This conclusion is not consistent with the results of groundwater modeling, and this inconsistency may be the result of local heterogeneity in rock properties that affect flow on a scale that cannot be duplicated in regional modeling. Like the Culebra, groundwater elevations in the Magenta have changed over the period of observation; in fact, the pattern of changes is similar to that observed for the Culebra and is attributed to the same causes (see Section 2.2.1.4 of the CCA, DOE 1996c).

Forty-Niner Member

The Forty-Niner Member is described as a confining hydrostratigraphic layer and consists of low-permeability anhydrite and siltstone about 20 meters (66 feet) thick throughout the WIPP area (DOE 1996c, Section 2.2.1.4). Tests reported in DOE (1996c) for H-14 and H-16 yielded transmissivities of about 3 x 10^{-8} to 8 x 10^{-8} square meters (3.23 x 10^{-7} to 8.61 x 10^{-7} square feet) per second and 3 x 10^{-9} to 6 x 10^{-9} square meters (3.23 x 10^{-8} to 6.46 x 10^{-8} square feet) per second, respectively. The porosity of the Forty-Niner was measured as part of the H-19 hydropad testing. Three claystone samples had effective porosities ranging from 9.1 to 24.0 percent, and four anhydrite samples had effective porosities ranging from 0.0 to 0.4 percent.

Rustler-Salado Contact Zone

The contact between the Rustler and Salado Formations in the vicinity of Nash Draw (see Figure 4-4) is of interest, because it provides evidence of earlier dissolution. It is an unstructured residuum of gypsum, clay, and sandstone created by the dissolution of halite and has been known as the brine aquifer or residuum. The residuum is absent under the WIPP site (DOE 1996c, Section 2.2.1.4).

Robinson and Lang (1938) suggested that the structural conditions that caused the development of Nash Draw might control the occurrence of the brine; thus, the brine aquifer boundary may coincide with the topographic surface expression of Nash Draw. Their studies show brine concentrated along a strip from 3.3 to 13 kilometers (2 to 8 miles) wide and about 43 kilometers (26 miles) long. Data from test holes indicate that the residuum containing the brine ranges in thickness from 3 to 18 meters (10.5 to 60 feet) and averages about 7 meters (24 feet).

Hydraulic properties for the area between Malaga Bend on the Pecos River and Laguna Grande de la Sal were estimated by Hale et al. (1954), who calculated a transmissivity value of 8.6×10^{-3} square meters (9.25×10^{-2} square feet) per second and estimated the potentiometric gradient to be 0.27 meter per kilometer (1.4 feet per mile). The coincident fluctuation of water levels in the area's test holes with pumping rates in irrigation wells along the Pecos River suggest the Rustler-Salado residuum to be part of a continuous hydrologic system.

In the northern half of Nash Draw, the approximate outline of the brine aquifer as described by Robinson and Lang (1938) has been supported by drilling associated with the WIPP hydrogeologic studies. These studies also indicate that the main differences in the aquifer's areal extent occur along the eastern side of Nash Draw where the boundary is very irregular and, in places (test holes P-14 and H-07), extends farther east than previously indicated. The recent studies also found a variability in thickness of residuum present in test holes WIPP-25 through WIPP-29, ranging from 3.3 meters (11 feet) in WIPP-25 to 33 meters (108 feet) in WIPP-29 in Nash Draw, as compared to 2.4 meters (8 feet) in test hole P-14 east of Nash Draw. The specific geohydrologic mechanism that has caused dissolution to be greater in one area than in another is not apparent, although a general increase in chloride concentration in water from the north to the south may indicate the effects of movement down the natural hydraulic gradient in Nash Draw.

The average hydraulic gradient within the residuum in Nash Draw is about 1.9 meters per kilometer (10 feet per mile). In contrast, the average gradient at the WIPP site is 7.4 meters per kilometer (39 feet per mile). This difference reflects the changes in transmissivity, which are as much as five orders of magnitude greater in Nash Draw. The transmissivity determined from aquifer tests in test holes completed in the Rustler-Salado contact residuum of Nash Draw ranges from 2.1×10^{-10} square meters (2.26×10^{-9} square feet) per second at WIPP-27 to 8.6×10^{-6} square meters (9.25×10^{-5} square feet) per second at WIPP-29. This is in contrast to the WIPP site proper, where transmissivities range from 3.2×10^{-11} square meters (3.44×10^{-10} square feet) per second at test holes P-18 and H-5c to 5.4×10^{-8} square meters (5.81×10^{-7} square feet) per second at test hole P-14 (DOE 1996c, Appendix HYDRO). Locations and estimated hydraulic heads of these wells are illustrated in the CCA (DOE 1996c, Figure 2-35).

Hale et al. (1954) believed the residuum discharges to the alluvium near Malaga Bend on the Pecos River. Because the confining beds in this area are probably fractured due to dissolution and collapse of the evaporites, the brine (under artesian head) moves up through these fractures into the overlying alluvium and then discharges into the Pecos River.

Water in the Rustler-Salado contact residuum in Nash Draw contains the largest concentrations of dissolved solids in the WIPP area, ranging from 41,500 milligrams per liter (5.63 ounces per gallon) in borehole H-1 to 412,000 milligrams per liter (55.9 ounces per gallon) in borehole H-5c (DOE 1996c, Appendix HYDRO). These waters are classified as brines. The dissolved mineral constituents in the brine consist mostly of sulfates and chlorides of calcium, magnesium, sodium, and potassium; the major cations and anions are sodium and chloride. Concentrations of the other major ions vary according to the areal location of the sample, are probably directly related to the interaction of the brine and the host rocks, and reflect residence time within the rocks. Residence time of the brine depends upon the transmissivity of the rock, that is, the presence of large concentrations of potassium and magnesium in water is correlated with minimal permeability and a relatively undeveloped flow system.

Dewey Lake and the Santa Rosa Formation Hydrology

The Dewey Lake and Santa Rosa Formations and surficial soils overlie the Rustler Formation and are the uppermost hydrostratigraphic units considered by DOE (DOE 1996c). A brief description of the main features of these units is provided below.

Dewey Lake Formation

The Dewey Lake Formation, also referred to as the Dewey Lake Redbeds, contains a productive zone of saturation, probably under water table conditions, in the southwestern to south-central portion of the WIPP site and south of the site. Several wells operated by the J.C. Mills Ranch south of the WIPP site produce sufficient quantities of water from the Dewey Lake to supply livestock. Short-term production rates of 5.7 to 6.8 cubic meters (1,500 to 1,800 gallons) per hour were observed in boreholes P-9, WQSP-6, and WQSP-6a (DOE 1996c, Appendix USDW). The saturated zone is typically found in the middle of the Dewey Lake, 55 to 81 meters (180 to 265 feet) below the surface and appears to derive much of its transmissivity from open fractures. The saturated zone may be perched or simply underlain by less transmissive rock. Fractures below the saturated zone tend to be completely filled with gypsum. Open fractures and/or moist (but not fully saturated) conditions have been observed at similar depths north of the saturation zone, at the H-1, H-2, and H-3 boreholes (DOE 1996c, Appendix HYDRO).

DOE estimated the position of the water table in the southern half of the WIPP site from an analysis of drillers' logs from three potash exploration boreholes and five hydraulic test holes. Using log records of the elevation of the first moist cuttings recovered during drilling, the elevation of the water table over the WIPP waste panels was estimated to be about 980 meters (3,215 feet) above sea level. In comparison, the repository lies 385 meters (1,260 feet) above sea level.

Santa Rosa Formation

The Santa Rosa Formation is absent over the western portion of the WIPP site and crops out northeast of Nash Draw. It is present over the eastern half of the WIPP site, where it reaches a thickness of 91 meters (300 feet). Near the WIPP site, the Santa Rosa may have a saturated thickness of limited extent. Its porosity is estimated at about 13 percent, and it has a specific capacity ranging from 0.029 to 0.041 liters per second per meter (2.3×10^{-3} to 3.3×10^{-3} gallons per second per foot) (DOE 1996c, Appendix HYDRO).

Potential Impacts of Karst and Dissolution Processes

The current understanding of the extent, timing, and features related to dissolution (including a brief history of past project studies related to karst) in the area surrounding WIPP is described in Section 2.1.6.2 of the CCA (DOE 1996c**)**. In summary, these studies and investigations show that the geomorphology of the region, particularly near Nash Draw and to a lesser extent near WIPP, has been influenced by shallow dissolution. Groundwater flow in the Culebra and other units of the Rustler is primarily controlled by fractures that have been affected by shallow dissolution processes. A significant proportion of the fractures within the Culebra are filled with secondary gypsum east of the WIPP; to the west of the site most fractures are open.

Groundwater basin modeling performed in the CCA suggests that the Culebra becomes progressively more confined toward the east, corresponding to an increase in the overburden towards the east. This is also thought to coincide with a decrease in the fracturing associated with dissolution at the Rustler-Salado boundary. Percolating groundwater has caused the lateral dissolution of halite at the top of the Salado, causing collapse of the overlying Rustler with consequent changes in hydrogeological properties. The most prominent lateral dissolution feature in the region is seen at Nash Draw, some 5 miles (8 kilometers) to the west of the WIPP site. Average rates calculated in previous investigations of karst indicate that dissolution at the top of the Salado at the edge of the WIPP site would not take place for some 225,000 years, and an additional 2 to 3 million years would be required for dissolution to reach the repository horizon.

Deep dissolution of salt or other evaporite minerals in formations near the WIPP site is distinguished from shallow and lateral dissolution not only by depth but also by the origin of the water. Groundwater originating from deep brine-bearing zones can lead to the formation of cavities at depths that could potentially cause the collapse of overlying beds. These processes could lead to the formation of collapse breccias if the overlying rocks are brittle or to deformation that causes fracturing if the overlying rocks are ductile. These pipes may reach the surface or pass upwards into fractures and then into cracks that do not extend to the surface. Breccia pipes may also form through the downward percolation of meteoric waters or accelerate contaminant transport from the repository by creating enhanced pathways of vertical flow that bypass low-permeability units in the Rustler. If dissolution occurred within or beneath the waste panels themselves, there could be increased circulation of groundwater through the waste and a breach of the Salado host rock.

Past investigations in the region have identified these types of deep dissolution features within the Delaware Basin; however, their occurrences have been limited to areas along the margins of the basin that are underlain by Capitan Reef. Because of these observations, deep dissolution is not expected to occur sufficiently close to WIPP nor to affect groundwater flow in the immediate region of WIPP during the period of regulatory concern.

Within Nash Draw, extensive fracturing of the Rustler allows more groundwater flow and, therefore, dissolution of the Rustler. East of Livingstone Ridge, there is less fracturing and dissolution in the Rustler. In the CCA, the Department has concluded that the extent of dissolution at the top of the Salado will not reach the controlled area until long after 10,000 years. Thus, shallow and deep dissolution at the WIPP site were not considered in the CCA performance assessment calculations.

Potential Hydrologic Effects of Natural Resource Exploration and Development Activities

The wide range of natural resource-related activities, which historically have been and will continue to be important in the region, have implications for future site impacts. The following is a brief description of the potential impacts of hydrocarbon exploration and development and potash mining.

Potential Impacts from Oil and Gas Development

Just outside of the WIPP site, oil and gas reserves are accessed by drilling through the Salado Formation and into the underlying oil- and gas-bearing formations. In the early 1990s, the Delaware Basin in the vicinity of the WIPP site experienced a significant increase in oil and gas exploration and development (Broadhead et al. 1995). Current restrictions do not allow any drilling activities within the WIPP controlled area, therefore, no direct impact from drilling activities is expected.

Hydrocarbon exploration and development, as a normal part of operations, also involves the injection of brine into boreholes that are used for brine disposal and enhanced oil recovery. The production of oil and gas is often accompanied by the production of large volumes of reservoir brine. Typically, the unwanted brine is injected back into the subsurface in an approved zone or zones through the use of salt water disposal wells. As oil, gas, and reservoir brine are produced in primary oil production, the natural reservoir energy will be expended and secondary methods such as water flooding are used to enhance crude oil recovery. A successful water flooding operation injects pressurized water through a well borehole into the oil bearing zone, to force additional oil to flow towards the producing well. Without proper management, both primary and secondary recovery methods can have significant hydraulic impact on surrounding geologic media.

In 1988, sudden water level changes were observed in wells completed in the Culebra Dolomite south of the WIPP site. Changes were first observed in Well H-9, about 10 kilometers (6 miles) south of the WIPP site (Figure 4-10). From 1988 through mid-1993, water levels steadily rose almost 5.5 meters (18 feet) before dropping abruptly. Water levels continued to drop until the end of 1995; currently, water levels are on the rise.

Analysis of the water level changes in H-9 and a number of other observation wells in areas north and south of WIPP and in the vicinity of WIPP have suggested that the changes in wells to the south are the result of possible hydraulic impacts of water flooding activities south of the WIPP site. Although there is no direct evidence to conclude which water flooding operation or what specific hydraulic condition is creating the specific water level changes observed near the WIPP site, casing leaks are the most logical pathway for introduction of fluid into the Rustler Formation.

The problem of injected water migrating out of the zone also occurs at other oil fields underlying the Salado Formation in the region.

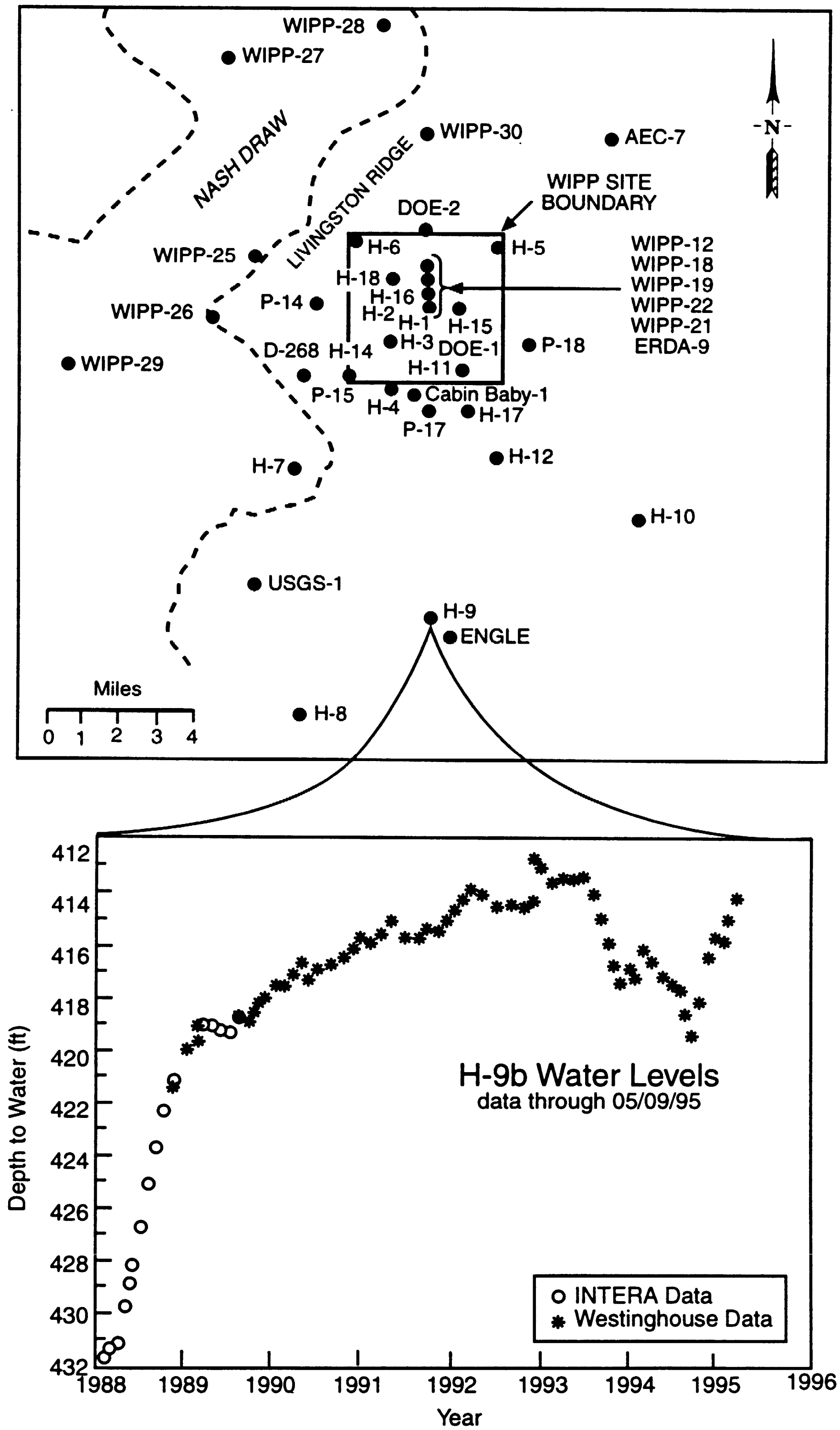


Figure 4-10
Locations of Wells Completed in the Culebra Dolomite in the Vicinity of the WIPP Site and Water-Level Changes in Observation Well H-9b between 1988 and 1996

Another example of potential hydrologic impacts from injection of large volumes of brine occurred in January, 1991 at a site located about 12 kilometers (8 miles) southeast of the WIPP site. In this incident, a borehole was in the process of being drilled through the Salado Formation when a salt water blowout, encountered at depths between 683 and 695 meters (2,240 and 2,280 feet), flowed uncontrollably for five days. In a lawsuit that followed, a claim was made that a nearby water flooding operation allowed large quantities of injected brine to escape out of an approved injection zone (which entered in the overlying Salado Formation) and migrate into the borehole. Evidence presented in the case substantiated the claim that brine injected to depths of about 915 meters (3,000 feet) had migrated out of the injection zone to the Salado Formation. The wells used in the water flooding operation were drilled and completed in the 1940s so the possibility of faulty well completion or failed well casing are potential causes of the out-of-injection zone migration. The potential for this type of incident to occur at WIPP was evaluated by DOE and was viewed as highly unlikely because of differences in geology between the WIPP site and the nearby site, changes in oil-well completion practices since the 1940s, and improved reservoir management practices.

The two examples of impacts noted above and other examples of the potential impacts of brine disposal and water flooding are described in more detail in Silva (1996).

Potential Impacts of Potash Mining

Potash mining has the potential to impact the hydrology of the area near the WIPP site in two ways. One impact involves the potential for mining operations and the development of room and pillar mines to cause weakening and collapse of overlying strata and subsequent subsidence. This may result in the propagation of fractures through both overlying water-bearing unit and potential contaminant pathways (e.g., the Culebra Dolomite), thereby increasing their hydraulic conductivity and potentially damaging petroleum well casings and uncased wells (Neill et al. 1996).

The other potential impact comes from the need of potash mining operations to dispose of brine generated during mining operations. As in the case of oil and gas drilling operations, potash mining requires the use of salt water disposal wells, and the potential exists that out-of-zone migration of brine injected through improperly sealed wells and deteriorating casing could have a potential impact on hydrologic conditions near the WIPP site.

Active and Passive Controls

The Department believes that planned active controls (see DOE 1996c, Chapter 7) will ensure that the prohibition on the drilling of hydrocarbon wells and on potash mining is enforced during the active institutional control period. For the purpose of this analysis, this period of active institutional control is assumed to be 100 years after the disposal operations period and site closure although it is the Department’s intention to maintain active institutional control well beyond this period. Beyond the active institutional period, DOE intends to implement a set of passive institutional controls (DOE 1996c, Section 7.3.4) that are expected to significantly deter the possibility of human intrusion for 700 years. Beyond that time, the effectiveness of passive controls is expected to degrade, and the potential exists for drilling or mining activities to encroach into the area of the WIPP site, leading to an intrusion from one or more exploratory boreholes or from mines into the repository and/or underlying possible pressurized brine reservoir. This potential impact was evaluated in the long-term performance assessment analysis described in Chapter 5 and Appendix H.